CHAPTER 3: MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3: MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter provides a profile of the distribution transformer industry in the United States. The Department developed the preliminary market and technology assessment presented in this chapter primarily from publicly available information. This assessment is helpful in identifying the major manufacturers and their product characteristics which form the basis for the engineering and the life-cycle-cost (LCC) analyses.

3.2 DISTRIBUTION TRANSFORMER DEFINITION

The Department's proposed definition of a distribution transformer includes specific definitions for each of the transformers excluded from the overall definition. This will clarify which transformers are covered. For seven of the transformers excluded from the Department's definition of a distribution transformer, definitions were adapted from Institute of Electrical and Electronics Engineers (IEEE) C57.12.80-2002: autotransformers, grounding transformers, machine-tool (control) transformers, non-ventilated transformers, rectifier transformers, regulating transformers, and sealed transformers. For K-factor transformers, the definition is adapted from Underwriters Laboratories (UL) UL1561 and UL1562. The Department developed the definitions for drive (isolation), the harmonic mitigating, special-impedance, testing, tap ranges greater than 15 percent, uninterruptible power supply, and welding transformers based on industry catalogues, practice, and nomenclature.

The Department proposes the following definition for a distribution transformer:

Distribution transformer means a transformer with a primary voltage of equal to or less than 35 kilovolts (kV), a secondary voltage equal to or less than 600 volts (V), a frequency of 55-65 Hertz (Hz), and a capacity of 10 kilovolt-amp (kVA) to 2500 kVA for liquid-immersed units and 15 kVA to 2500 kVA for dry-type units, and does not include the following types of transformers: (1) autotransformer; (2) drive (isolation) transformer; (3) grounding transformer; (4) harmonic mitigating transformer; (5) K-factor transformer; (6) machine-tool (control) transformer; (7) non-ventilated transformer; (8) rectifier transformer; (9) regulating transformer; (10) sealed transformer; (11) special-impedance transformer; (12) testing transformer; (13) transformer with tap range greater than 15 percent; (14) uninterruptible power supply transformer; or (15) welding transformer.

Definitions for each of the 15 transformers not considered to be a distribution transformer appear below:

Autotransformer means a transformer that: (a) has one physical winding that consists of a series winding part and a common winding part; (b) has no isolation between its primary and secondary circuits; and (c) during step-down operation, has a primary voltage that is equal to the total of the series and common winding voltages, and a secondary voltage that is equal to the common winding voltage.

Drive (isolation) transformer means a transformer that: (a) isolates an electric motor from the line; (b) accommodates the added loads of drive-created harmonics; and (c) is designed to withstand the additional mechanical stresses resulting from an alternating current adjustable frequency motor drive or a direct current motor drive.

Grounding transformer means a three-phase transformer intended primarily to provide a neutral point for system-grounding purposes, either by means of: (a) a grounded wye primary winding and a delta secondary winding; or (b) an autotransformer with a zig-zag winding arrangement.

Harmonic mitigating transformer means a transformer designed to cancel or reduce the harmonics drawn by computer equipment and other non-linear power electronic loads.

K-factor transformer means a transformer with a K-factor of 13 or greater that is designed to tolerate the additional eddy-current losses resulting from harmonics drawn by non-linear loads, usually when the ratio of the non-linear load to the linear load is greater than 50 percent.

Machine-tool (control) transformer means a transformer that is equipped with a fuse or other overcurrent protection device, and is generally used for the operation of a solenoid, contactor, relay, portable tool, or localized lighting.

Non-ventilated transformer means a transformer constructed to prevent external air circulation through the coils of the transformer while operating at zero gauge pressure.

Rectifier transformer means a transformer that operates at the fundamental frequency of an alternating-current system and that is designed to have one or more output windings connected to a rectifier.

Regulating Transformer means a transformer that varies the voltage, the phase angle, or both voltage and phase angle, of an output circuit and compensates for fluctuation of load and input voltage, phase angle, or both voltage and phase angle.

Sealed Transformer means a transformer designed to remain hermetically sealed under specified conditions of temperature and pressure.

Special-impedance transformer means any transformer built to operate at an impedance outside of the normal impedance range for that transformer's kVA rating. The normal impedance range for each kVA rating is shown in Tables 3.2.1 and 3.2.2.

Table 3.2.1 Normal Impedance Ranges for Liquid-Immersed Transformers

Single-Phase Transformers		Three-Phase Transformers	
kVA	Impedance (%)	kVA	Impedance (%)
10	1.0-4.5	15	1.0-4.5
15	1.0-4.5	30	1.0-4.5
25	1.0-4.5	45	1.0-4.5
37.5	1.0-4.5	75	1.0-5.0
50	1.5-4.5	112.5	1.2-6.0
75	1.5-4.5	150	1.2-6.0
100	1.5-4.5	225	1.2-6.0
167	1.5-4.5	300	1.2-6.0
250	1.5-6.0	500	1.5-7.0
333	1.5-6.0	750	5.0-7.5
500	1.5-7.0	1000	5.0-7.5
667	5.0-7.5	1500	5.0-7.5
833	5.0-7.5	2000	5.0-7.5
		2500	5.0-7.5

Table 3.2.2 Normal Impedance Ranges for Dry-Type Transformers

Single-Phase Transformers		Three-Phase Transformers	
kVA	Impedance (%)	kVA	Impedance (%)
15	1.5-6.0	15	1.5-6.0
25	1.5-6.0	30	1.5-6.0
37.5	1.5-6.0	45	1.5-6.0
50	1.5-6.0	75	1.5-6.0
75	2.0-7.0	112.5	1.5-6.0
100	2.0-7.0	150	1.5-6.0
167	2.5-8.0	225	3.0-7.0
250	3.5-8.0	300	3.0-7.0
333	3.5-8.0	500	4.5-8.0
500	3.5-8.0	750	5.0-8.0
667	5.0-8.0	1000	5.0-8.0
833	5.0-8.0	1500	5.0-8.0
		2000	5.0-8.0
		2500	5.0-8.0

Testing Transformer means a transformer used in a circuit to produce a specific voltage or current for the purpose of testing electrical equipment. This type of transformer is also commonly known as an instrument transformer.

Transformer with Tap Range greater than 15 percent means a transformer with a tap range in the primary winding greater than the range accomplished with six 2.5 percent taps, three above and three below rated primary voltage (e.g., six times 2.5 percent = 15 percent).

Uninterruptible Power Supply Transformer means a transformer that supplies power to an uninterruptible power system, which in turn supplies power to loads that are sensitive to power failure, power sags, over-voltage, switching transients, line noise, and other power quality factors.

Welding Transformer means a transformer designed for use in arc welding equipment or resistance welding equipment.

3.3 PROPOSED PRODUCT CLASSES

For the standards rulemaking, the Department separated transformers into product classes according to their capacity or other performance-related features or attributes, including those that provide utility to the end-user or inherently affect efficiency. The Department sought comments from stakeholders on product classes in the Framework Document Workshop held in November 2000. Based on this feedback, the Department created ten proposed product classes, shown in Table 3.3.1, applying the following four criteria:

a) Type of Transformer Insulation - liquid-immersed or dry-type,
b) Number of Phases - single or three,
c) Voltage Class - low or medium (for dry-type units only), and
d) Basic Impulse Insulation Level (for medium-voltage, dry-type units only).

Table 3.3.1 Proposed Distribution Transformer Product Classes

Number	Insulation	Voltage	Phase	BIL Rating	kVA Range
1	Liquid-Immersed	Medium	Single	-	10-833 kVA
2	Liquid-Immersed	Medium	Three	-	15-2500 kVA
3	Dry-Type	Low	Single	-	15-333 kVA
4	Dry-Type	Low	Three	-	15-1000 kVA
5	Dry-Type	Medium	Single	20-45kV BIL	15-833 kVA
6	Dry-Type	Medium	Three	20-45kV BIL	15-2500 kVA
7	Dry-Type	Medium	Single	46-95kV BIL	15-833 kVA
8	Dry-Type	Medium	Three	46-95kV BIL	15-2500 kVA
9	Dry-Type	Medium	Single	≥96kV BIL	75-833 kVA
10	Dry-Type	Medium	Three	≥96kV BIL	225-2500 kVA

Basic impulse insulation levels (BIL) refer to the level of insulation wound into a transformer, dictating its design voltage. Generally, higher BIL ratings have lower transformer operating efficiencies because the additional insulation and necessary clearances increase the distance between the core steel and the windings, making the magnetic fields travel further, and thereby contributing to higher losses. In addition, as the overall size of the windings increases due to additional insulation surrounding each wire, the core-window through which the windings pass must increase, creating a larger core and increasing losses in the core. Recognizing this important aspect of transformer design, and after consultation with industry experts, the Department determined that differentiation of the energy efficiency standards by BIL level would be necessary for medium-voltage, dry-type units as these transformers experience significant variability in efficiency due to their BIL ratings. This decision is consistent with NEMA's TP 1-2002 (described in section 3.7.1).

3.4 NATIONAL SHIPMENT ESTIMATE

To calculate reasonably accurate national energy savings estimates, the Department required disaggregated shipment estimates by product class and kVA rating within each product class. This information is considered highly sensitive by manufacturers, many of whom indicated to the Department they were not willing to disclose that information. The Department reviewed shipments data from the Census Bureau, but found that the data are aggregated at a high level, grouping together dozens of kVA ratings in one value. Thus, the Department determined that it would not be possible to create a meaningful and reasonably accurate estimate of shipments at the product class, kVA rating using Census Bureau data.

Thus, the Department followed a different approach, soliciting a national shipment estimate from an expert with considerable knowledge of the U.S. transformer industry. The

Department selected a contractor with more than 80 years of experience working in both the liquid-immersed and dry-type transformer industry in the U.S. The national shipment estimates were generated by the contractor, using both knowledge of the market and a limited number of consultative calls with other industry experts. Figures 3.4.1 through 3.4.4 present the total aggregate shipment estimate for liquid-immersed and dry-type units. A detailed breakdown of the shipment estimates by product class and kVA rating appears in section 9.3.1 of the shipments analysis (Chapter 9 of this TSD).

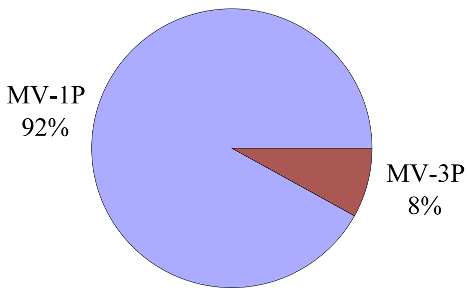

Figure 3.4.1 Liquid-Immersed Unit Shipments

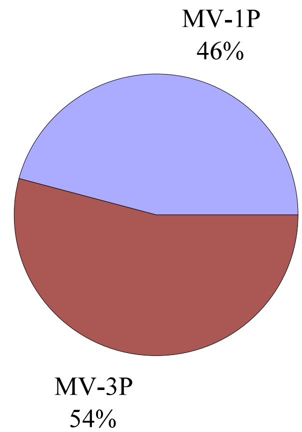

Figure 3.4.2 Liquid-Immersed MVA Capacity Shipments

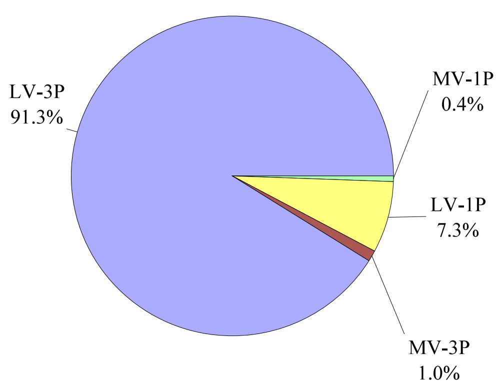

Figure 3.4.3 Dry-Type Unit Shipments

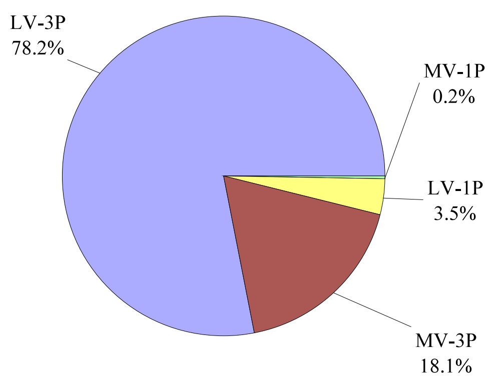

Figure 3.4.4 Dry-Type MVA Capacity Shipments

These pie charts show the estimated shipments for 2001 in both number of transformers and cumulative MVA of transformer capacity. Figures 3.4.1 and 3.4.2 divide the liquid-immersed market into two principal product classes: medium-voltage, single-phase (MV-1P) and medium-voltage, three-phase (MV-3P). Figures 3.4.3 and 3.4.4 divide the dry-type market into low-voltage, single-phase (LV-1P); low-voltage, three-phase (LV-3P); medium-voltage, single-phase (MV-1P), and medium-voltage, three-phase (MV-3P). To simplify the illustrations, the MV-1P and MV-3P dry-type units are shown each as aggregations of the three medium-voltage, dry-type product classes presented in table 3.3.1, where they are broken down by BIL rating. This was necessary as the separate market shares of medium-voltage, dry-type by BIL rating are small compared to the low-voltage, dry-type units.

Table 3.4.1 presents the actual shipment estimates by product class and the estimated value of these shipments, approximately $1.6 billion in 2001.

Table 3.4.1 National Distribution Transformer Shipment Estimates for 2001

Distribution Transformer Product Class	Units Shipped	MVA Capacity Shipped	Shipment Value (2001 US$million)
Liquid-immersed, medium-voltage, single-phase	977,388	36,633	698.8
Liquid-immersed, medium-voltage, three-phase	79,367	42,887	540.4
Dry-type, low-voltage, single-phase	23,324	983	17.8
Dry-type, low-voltage, three-phase	290,818	21,909	235.0
Dry-type, medium-voltage, single-phase, 20-45 kV BIL	119	18	0.5
Dry-type, medium-voltage, three-phase, 20-45 kV BIL	650	776	13.5
Dry-type, medium-voltage, single-phase, 46-95 kV BIL	121	22	0.6
Dry-type, medium-voltage, three-phase, 46-95 kV BIL	2,371	3,913	68.1
Dry-type, medium-voltage, single-phase, ≥96 kV BIL	20	4	0.1
Dry-type, medium-voltage, three-phase, ≥96 kV BIL	187	367	6.4
Total	1,374,366	107,512	1,581.2

The liquid-immersed transformer market accounted for 77 percent of the distribution transformers sold in the United States in 2001 (on a unit basis). These transformers accounted for 74 percent of the distribution transformer capacity measured in megavolt-amperes (MVA), and 78 percent of the dollar value of the 2001 shipments. On a unit basis, more than 90 percent of the liquid-immersed shipments are single-phase units. However, these single-phase units tend to have lower kVA ratings than the three-phase units, which are more than half of the total MVA capacity shipped of liquid-immersed distribution transformers in 2001.

In the dry-type market, low-voltage, three-phase distribution transformers dominate, accounting for 91 percent of units and 78 percent of MVA shipped. Medium-voltage, three-phase units accounted for only one percent of the units shipped, but were 18 percent of MVA shipments in 2001. The low-voltage, single-phase units were about seven percent of the dry-type units shipped; however, because their kVA ratings tend to be small, they only accounted for about 3.5 percent of the cumulative dry-type MVA shipments in 2001. Medium-voltage, single-phase units occupy a small part of the market, representing less than one-half of one percent of both units and MVA shipped.

In preparing their estimates of the distribution transformer market, the Department's contractor identified differences between its 2001 shipment estimates and the Oak Ridge National Laboratory (ORNL) Determination Analysis shipment estimates for 1995.[1] The differences and the understanding behind some of these differences are discussed below.

1. Compared to 1995, the 2001 shipment data suggest that more single-phase, liquid-immersed transformers were purchased as pad-mounts in 2001 than in 1995. Total single-phase, liquid-immersed transformer shipments remained close to the traditional one million units per year; however the average kVA size has risen in both pole- and pad-mounted transformers by approximately ten percent between 1995 and 2001.

2. The three-phase, liquid-immersed transformer market was considerably larger in 2001 than in 1995. This difference could be attributed to a more robust commercial and industrial expansion in 2001 compared to 1995.

3. The single-phase, low-voltage, dry-type transformer shipment estimates are approximately the same as the ORNL 1995 estimates, but the majority of ratings under 37.5 kVA are sand-resin type. Sand-resin type (also called epoxy-potted) transformers, under the Department's proposed definition, are not considered distribution transformers. The ORNL 1995 shipment estimates probably included sand-resin type transformers, due to the magnitude of the estimate.

4. There were more shipments of three-phase, low-voltage, dry-type transformers in 2001 compared with 1995, paralleling shipment growth in three-phase liquid-immersed transformers.

5. The three-phase, medium-voltage, dry-type transformer market was smaller in volume than ORNL determined in 1995, but with larger kVA ratings. These larger three-phase, medium voltage, dry-type distribution transformers are most commonly used inside commercial and industrial buildings when power requirements are sufficiently large that direct feed from a liquid-immersed external transformer would be uneconomical.

3.5 MANUFACTURERS OF DISTRIBUTION TRANSFORMERS

In total, there are more than 92 manufacturers and importers of distribution transformers operating in the U.S. today.[a] Of these, sixteen major companies represent about 80 percent of both the liquid-immersed and dry-type markets.

From a manufacturing point of view, the six largest companies operating in the liquid-immersed distribution transformer market are (in alphabetical order): ABB Power T&D Company, Cooper Power Systems, ERMCO, General Electric Power Systems, Howard Industries, and Kuhlman Electric Corporation. Together, these six companies represent more than 80 percent of the sales revenue of liquid-immersed distribution transformers in the U.S.

For dry-type distribution transformer manufacturers, the ten largest companies operating in the U.S. include (in alphabetical order): ABB Power T&D Company, Acme Electric Corporation, Eaton Electrical, Inc., Federal Pacific Transformer Company, Hammond Power Solutions Inc., Jefferson Electric Inc., MGM Transformer, Olsun Electrics Corporation, Sola/Hevi-Duty, and Square D Company. Together, these companies represent more than 80 percent of the sales revenue of dry-type distribution transformers in the U.S.

3.5.1 Potential Small Business Impacts

The Department is considering the possibility of small businesses being impacted by the promulgation of minimum efficiency standards for distribution transformers. The Department is aware that there are small distribution transformer manufacturers, as defined by the Small Business Administration, who would be impacted by a minimum efficiency standard. The Department will study the impacts to these small businesses in greater detail during the manufacturer impact analysis, which it will conduct as part of the NOPR analysis.

3.5.2 Distribution and Sales Channels

A schematic of the structure of the distribution transformer market is shown in Figure 3.5.1.[1] This illustration depicts the major market players and the level of interaction between each. The solid lines show more common distribution and sales channels and dashed lines less frequently used channels.

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[a] This estimate is based on a review of the Thomas Business Registry (August 2001), the ORNL contact database from the Determination Analysis[1] and participants in DOE's Distribution Transformers Framework Workshop meeting held November 1, 2000 in Washington, DC.

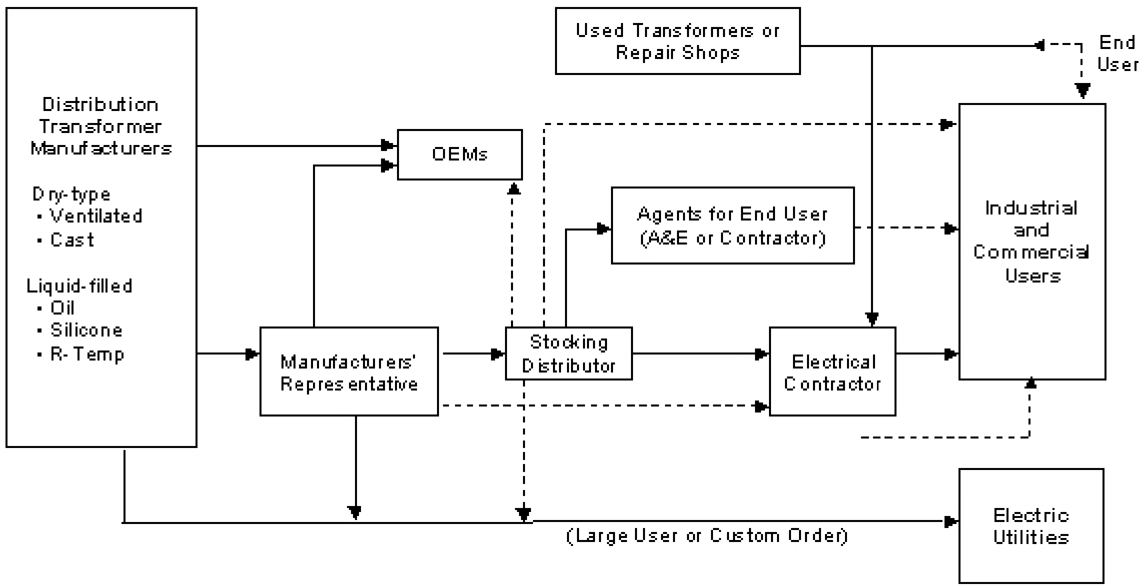

Figure 3.5.1 Market Delivery Channels for Distribution Transformers

Source: ORNL, *Determination Analysis of Energy Conservation Standards for Distribution Transformers*, 1996.

The market delivery channel for electric utilities is generally direct, with the majority of these customers placing orders directly with manufacturers. It is estimated that electric utilities purchase over 90 percent of their distribution transformers directly from manufacturers, specifying their desired features and performance.[1] There are also utilities who make transformer purchases through distributors, such as some rural cooperatives and municipalities. When placing an order, the electric utility provides a specification, including the value it places on future core and coil losses over the life of the transformer (see Section 3.6 for a discussion of total owning cost). This market dynamic leads manufacturers to develop custom designs in their contract bid, reflecting the customer's performance requirements and the dynamic costs of material, equipment and labor at a transformer manufacturer's facility.

The delivery channel for commercial and industrial customers can be complex, working through intermediaries such as stocking distributors and electrical contractors. Electrical contractors typically purchase transformers using specifications written by themselves or by agents. Some larger industrial customers buy transformers directly from distributors or manufacturers based on specifications drafted by in-house experts. Any large-volume or custom-order purchases made (e.g., orders from the petrochemical or the pulp and paper industry) are typically made directly with transformer manufacturers. Similarly, original equipment manufacturers (OEMs) know the exact specification they require for their finished products and typically work directly with manufacturers when placing an order.

Transformers with major damage are usually replaced rather than repaired. However, when a repair does take place, it may be carried out by a repair shop or at the manufacturer's facility (e.g., when failure occurs within the warranty period). Additionally, some utilities may choose to carry out their own repairs if this option is less expensive than disposal and replacement.

3.5.3 Import Duties on Core Steel

Import duties are applied to core steels originating in Japan and Italy. This duty is levied at the port of entry, and amounts to a 31 percent anti-dumping duty. Generally, domestic suppliers are able to offer equivalent specification core steels without the duty, however one particular type of steel manufactured by Nippon Steel Corporation in Japan is patented, and is not available to U.S. transformer manufacturers without the 31 percent duty. This electrical steel, known as ZDMH, is a high-permeability, mechanically-scribed electrical steel, with lower losses than conventional core steels. The mechanical scribing process reduces the losses, making it the most efficient conventional core steel for wound-core construction.

Mexico and Canada do not apply this 31 percent import duty to electrical steel, enabling manufacturers in these neighboring countries to produce transformers with ZDMH at a lower cost (the steel is not taxed if incorporated into a finished product). Thus, manufacturers in these countries have a competitive cost advantage of 31 percent on core steel, the most expensive part of a distribution transformer. For this reason, the Department analyzed two price points for designs using ZDMH, to make sure that when considering the appropriate standard level, it does not regulate to a point where U.S. manufacturers would have a competitive disadvantage. The two price points are for ZDMH purchased in Mexico or Canada and ZDMH purchased in the United States. The prices used for this core steel (discussed in Chapter 5) reflect the 31 percent tariff: $1.40 per pound in Mexico and Canada and $1.83 per pound for a U.S. manufacturer.

3.6 TOTAL OWNING COST EVALUATION

In 1995, it was estimated that there were approximately 44 million liquid-immersed distribution transformers in service, of which approximately 90 percent were owned by electric utilities.[1] For dry-type transformers, there were approximately 12 million units in service, which were primarily used by commercial and industrial customers.[1] The liquid-immersed market, dominated by the electric utility sector, drove efficiency ratings higher over time, encouraging more efficient materials and manufacturing methods. A detailed discussion of these improvements and efficiency trends between the years 1950 and 1993 can be found in two Oak Ridge National Laboratory Reports.[1, 2]

Following the energy price shocks of the 1970s, utilities started using total owning cost (TOC) evaluation formulae (Equation 3.1), incorporating core and winding losses into their purchasing decisions. The TOC consists of the quoted transformer price and energy losses in the core and winding over the anticipated life of the unit.

Expressed as a formula,

$$TOC = (NL \times A) + (LL \times B) + Price \qquad \textbf{Eq. 3.1}$$

where:

TOC	total owning cost ($),
NL	no-load loss (Watts),
A	equivalent first-cost of no-load losses ($/Watt),
LL	load loss at the transformer's rated load (Watts),
B	equivalent first-cost of load losses ($/Watt), and
Price	bid price (retail price)($).

The capitalized cost per watt of no-load and load losses, the A and B factors, vary from one electric utility to another. They are derived from several variables, including the avoided costs of system capacity, generation capacity, transmission and distribution capacity and energy, the levelized fixed charge rate, the peak responsibility factor, the transformer loss factor and the equivalent annual peak load.[3] For a detailed discussion on the development and use of the TOC formula, including examples, see the proposed draft industry standard document, IEEE PC57.12.33.

Utilities who use A and B factors will compare two or more proposals from manufacturers and select the one that offers them the lowest total owning cost — i.e., the lowest combination of first cost and operating cost over the life of the transformer. Before electric utility deregulation started in North America, 30 years was considered the operating life and the depreciation period of a liquid-immersed transformer. In the last five years, deregulation has raised concerns about payback periods as electric utilities are not sure if they will own the transformer for its entire life. This uncertainty has forced some electric utilities to reduce their A and B factors, equating to a decreased emphasis on losses, and therefore a reduction in transformer efficiency ratings.

In 1996, ORNL estimated that "more than 90 percent" of electric utilities used the TOC method of loss evaluation at the time of purchase, which drove the market toward increasingly efficient designs.[1] More recently, however, the possibility of deregulation and the associated sale of distribution networks has meant that utilities purchasing transformers today may not own them in five or ten years, and thus won't recover the higher initial cost of a more efficient design. These regulatory changes and the general uncertainty surrounding deregulation has driven some utilities to purchase designs with lower first costs and higher losses. A more recent estimate of the percentage of electric utilities using the TOC loss evaluation formula is 50 percent for 2001.[4]

The IEEE proposed standard PC57.12.33 has a chapter discussing transformer efficiency for commercial and industrial customers[3] (i.e., typical users of dry-type transformers), but the market itself appears dichotomous, split between the medium-voltage and the low-voltage units. The medium-voltage, dry-type transformer market functions similarly to the liquid-immersed market, in that manufacturers receive custom-build orders with specifications or design criteria from the customer. Because these customers pay for (and are concerned about) the electricity lost in their own distribution systems, they are concerned about the performance of the transformers they order. The low-voltage, dry-type transformer market does not participate in the manufacturing process; instead these units are generally sold "off-the-shelf" or on a catalogue/stock order basis. Most of the low-voltage, dry-type transformers installed inside buildings or plants are purchased by electrical contractors or building managers who are not responsible for paying future energy bills. Thus, the designs of these transformers are commonly driven toward the lowest first-cost, lower efficiency units. This trend was identified by ORNL.[1]

3.7 VOLUNTARY PROGRAMS

The Department reviewed several voluntary programs promoting efficient distribution transformers in the United States. These include the National Electrical Manufacturers Association (NEMA) TP 1 Standard, the U.S. Environmental Protection Agency's Energy Star Transformers program and the Federal Energy Management Program's TP 1 purchase program. The Department also reviewed several voluntary programs affecting distribution transformers that are operating at a regional level, including the New York State Energy Research and Development Authority, National Grid, Northeast Utilities, Northeast Energy Efficiency Partnership, Sacramento Municipal Utility District, United Illuminating, Wisconsin Public Power and Xcel Energy.

3.7.1 National Electrical Manufacturers Association TP 1 Standard

The NEMA TP 1 standard establishes a voluntary efficiency standard for distribution transformers.[5] It encompasses liquid-immersed distribution transformers, single- and three-phase as well as dry-type, low-voltage and medium-voltage, single- and three-phase. NEMA established this national voluntary efficiency standard in 1996, and revised it in 2002. Manufacturers must meet or exceed the minimum efficiency targets presented in Tables 3.7.1 and 3.7.2 at the appropriate loading points. TP 1 efficiency levels are adopted by states and other agencies who are interested in establishing a standard. At a national level, the U.S. Congress is considering the TP 1 standard for low-voltage dry-types (the draft Energy Bill is discussed briefly in section 3.8.8). More information about TP 1 can be obtained by contacting NEMA, tel: 703-841-3200, or by visiting http://www.nema.org/index_nema.cfm/1427/47168E11-AA56-4B4E-9F329B339C23F115/.

Table 3.7.1 NEMA Efficiency Levels for Liquid-Immersed Distribution Transformers

Liquid-Immersed, Single-Phase		Liquid-Immersed, Three-Phase	
kVA	Min Efficiency (%)	kVA	Min Efficiency (%)
10	98.3	15	98.0
15	98.5	30	98.3
25	98.7	45	98.5
37.5	98.8	75	98.7
50	98.9	112.5	98.8
75	99.0	150	98.9
100	99.0	225	99.0
167	99.1	300	99.0
250	99.2	500	99.1
333	99.2	750	99.2
500	99.3	1000	99.2
667	99.4	1500	99.3
833	99.4	2000	99.4
-	-	2500	99.4

Notes: Temperature: load-loss 85ºC, no-load loss 20ºC
Efficiency levels at 50 percent of unit nameplate load

Table 3.7.2 NEMA Efficiency Levels for Dry-Type Distribution Transformers

Dry-Type, Single-Phase				Dry-Type, Three-Phase			
kVA	Min Efficiency (%)			kVA	Min Efficiency (%)		
	Low-Voltage	Medium-Voltage			Low-Voltage	Medium-Voltage	
		≤60 kV BIL	>60 kV BIL			≤ 60 kV BIL	> 60kV BIL
15	97.7	97.8	97.6	15	97.0	97.2	96.8
25	98.0	98.1	97.9	30	97.5	97.6	97.3
37.5	98.2	98.3	98.1	45	97.7	97.8	97.6
50	98.3	98.4	98.2	75	98.0	98.1	97.9
75	98.5	98.5	98.4	112.5	98.2	98.3	98.1
100	98.6	98.6	98.5	150	98.3	98.4	98.2
167	98.7	98.8	98.7	225	98.5	98.5	98.4
250	98.8	98.9	98.8	300	98.6	98.6	98.5
333	98.9	99.0	98.9	500	98.7	98.8	98.7
500	-	99.1	99.0	750	98.8	98.9	98.8
667	-	99.2	99.0	1000	98.9	99.0	98.9
833	-	99.2	99.1	1500	-	99.1	99.0
-	-	-	-	2000	-	99.2	99.0
-	-	-	-	2500	-	99.2	99.1

Notes: Temperature75ºC for both low- and medium-voltage
Low-voltage efficiency levels at 35 percent of unit nameplate load
Medium-voltage efficiency levels at 50 percent of unit nameplate load

3.7.2 ENERGY STAR® Transformers

The U.S. Environmental Protection Agency (USEPA) and the DOE manage a program called ENERGY STAR® Transformers to overcome market barriers preventing industrial/commercial customers and utilities from purchasing more energy efficient dry-type, low-voltage, single- and three-phase units. The minimum efficiency that a transformer must meet or exceed in order to be classified as an ENERGY STAR® transformer is the same as NEMA's TP 1. The activities of this program include the ENERGY STAR® label, marketing assistance to manufacturers and distributors, and free software tools for end users (including a downloadable cost evaluation model and an energy-efficiency calculator). This program is sponsored and promoted by the USEPA and DOE, with additional promotional support from the Consortium for Energy Efficiency. For more information about this program, please contact the USEPA tel: 1-888-STAR-YES or the Consortium for Energy Efficiency, tel: 617-589-3949.

3.7.3 Federal Energy Management Program

The Department manages the Federal Energy Management Program (FEMP), which helps Federal buyers identify and purchase energy-efficient equipment, including distribution transformers. The FEMP standard for distribution transformers is based on the NEMA TP 1 standard, and includes all units listed in TP 1. FEMP offers buyers support tools such as efficiency guidelines, cost-effectiveness examples, and a cost calculator. FEMP also offers training, on-site audits, demonstrations, and design assistance. For more information, interested stakeholders can contact FEMP at tel: 1-800-363-3732.

3.7.4 New York State Energy Research and Development Authority

The New York State Energy Research and Development Authority (NYSERDA) manages the New Construction Program and the Smart Equipment Choices Program, which work to educate electrical system designers, electrical contractors, corporate facility planners, and building developers about Energy Star transformers and their benefits.[6] These programs previously offered short-term incentives to create demand, focusing on NEMA TP 1 dry-type distribution transformers. However, the Energy Conservation Construction Code of New York State mandated the NEMA TP 1 standard for distribution transformers; therefore, as of July 2002, NYSERDA removed the incentives for TP 1 transformers under these two programs.

The NYSERDA has continued some incentives under the New Construction Program for distribution transformers exceeding the TP 1 standard. NYSERDA calculates incentives based on the energy-saving opportunities identified for a specific project. Incentives are capped at 70 percent of the incremental cost and NYSERDA will only reduce a participant's costs to a one-year payback. Custom incentives for installing TP 1 transformers in retrofit applications are also available from NYSERDA. The level of incentive for retrofits is performance-based, i.e., based on verified annualized kWh savings for up to a two-year period following project installation. For more information, contact NYSERDA at tel: 518-862-1090.

3.7.5 National Grid

National Grid manages the Design 2000 Plus and the Energy Advantage New Hampshire Programs, which both work to promote energy efficiency in design and construction practices in new and renovated commercial and industrial buildings.[7] The target equipment of these programs are NEMA TP 1 dry-type, low-voltage, three-phase units. The programs offer rebates in Rhode Island and New Hampshire territories (the participating utilities are Narragansett Electric and Granite State, respectively). These rebates cover 75 percent of a compliant transformer's incremental cost over the least expensive TP 1 model, or they buy down the unit cost until it offers a 1.5-year payback. The maximum rebate amounts are presented in Table 3.7.3. The program also offers training for transformer specifiers and provides marketing activities to promote Energy Star units. For more information, contact National Grid at tel: 508-389-2000.

Table 3.7.3 National Grid Design 2000 Rebate Amounts

Dry-Type, Low-Voltage, Single-Phase			
kVA	Maximum incentive per unit	kVA	Maximum incentive per unit
15	$130	112.5	$520
30	$190	150	$560
45	$225	225	$1150
75	$440	-	-

3.7.6 Northeast Utilities

Northeast Utilities manages the Energy Conscious Construction Program which provides incentives to builders and contractors to support the purchase of energy-efficient transformers.[8] The target equipment of this standard are NEMA TP 1 dry-type, low-voltage, three-phase distribution transformers. The program focuses its efforts on projects within the customer area of Northeast Utilities, covering 70 to 100 percent of the additional incremental cost for a TP 1 transformer, depending on measured energy savings. The maximum rebate amounts available are presented in Table 3.7.4. For more information, contact Northeast Utilities at tel: 1-800-286-5000.

Table 3.7.4 Northeast Utilities Energy Conscious Construction Rebate Amounts

Dry-Type, Low-Voltage, Three-Phase			
kVA	Maximum incentive per unit	kVA	Maximum incentive per unit
15	$640	150	$1140
30	$480	225	$1440
45	$570	300	$1800
75	$670	500	$2550
112.5	$700	-	-

3.7.7 Northeast Energy Efficiency Partnership

The Northeast Energy Efficiency Partnership (NEEP) manages a program called Energy Star Customer Side Transformers.[9] This program works to promote Energy Star transformers and make them the standard for all new customer-side commercial and industrial construction in the Northeastern United States. The activities of this program include information and marketing campaigns and training for contractors and building owners. In addition to NEEP, this program is co-sponsored by NStar, Massachusetts Electric and the U.S. Environmental Protection Agency. For more information, contact NEEP at tel: 1-781-860-9177.

3.7.8 Sacramento Municipal Utility District

The Sacramento Municipal Utility District (SMUD) manages the Commercial and Industrial Retrofit Program, which works to reduce peak demand of commercial and industrial customers.[10] This program advocates Energy Star transformers, offering financial incentives to accelerate market adoption. SMUD offers $300 per average kW saved from 1:00 p.m. to 9:00 p.m., not to exceed 40 percent of the project cost, or $30,000 per year, per customer account. Incentives for retrofit applications are likely to continue, notwithstanding the adoption of statewide appliance standards that mandate NEMA TP-1 standards. For more information, contact SMUD at tel: 1-888-742-7683.

3.7.9 United Illuminating

United Illuminating manages an energy-efficiency initiative in Connecticut called the Energy Blueprint Program.[11] This program works to promote energy-efficient buildings and commercial equipment, including lighting, building envelope, Heating Ventilation & Air Conditioning (HVAC) equipment, motors, and other energy components of commercial and industrial systems. For transformers, Energy Blueprint promotes Energy Star transformers. The program offers cash incentives ranging from $640 to $2,550. For more information, contact United Illuminating at tel: 1-800-722-5584.

3.7.10 Wisconsin Public Power

Wisconsin Public Power manages a program called the Energy Star Transformer Incentive.[12] This program is based on Energy Star transformers. A cash incentive is provided, based on realized energy savings. Before purchasing a transformer, the buyer must contact one of the sponsoring electric utilities to receive a rebate for purchasing a TP 1 transformer. For more information, contact Wisconsin Public Power at tel: (608) 834-4500.

3.7.11 Xcel Energy

Xcel Energy manages the Custom Efficiency Program in Minnesota to help reduce peak load demand of commercial and industrial customers.[13] Based on the NEMA TP 1 standard for low- and medium-voltage, dry-type distribution transformers, this program offers financial incentives of up to US$200 per kilowatt of average demand savings achieved during the system peak period by utilizing an energy efficient distribution transformer. For more information, contact Xcel Energy at tel: 1-800-328-8226.

3.8 REGULATORY PROGRAMS

The Department is aware of state-level regulatory programs that impact the distribution transformer market in California, Massachusetts, Minnesota, New York, Oregon, Vermont, and Wisconsin. In addition, on a national level, Congress is presently considering efficiency standards at the NEMA TP 1 level for low-voltage, dry-type distribution transformers. If this bill were to become law, it would preempt the Department's rulemaking process for low-voltage, dry-type transformers only. Rulemaking analysis would continue on the medium-voltage, dry-type and the liquid-immersed distribution transformers. At the international level, the Department is aware of standards in both Canada and Mexico that may impact the companies servicing the North American market. Summaries of all these regulatory programs are provided in this section.

3.8.1 California Efficiency Standard

The Title 20 Appliance Efficiency Standards regulation mandates that transformers manufactured after March 1, 2003 and sold in California be NEMA TP 1 compliant.[14] Title 20 was approved by the California Energy Commission in November 2002; final approval is pending litigation initiated by trade associations of federally covered products. A subsequent round of legislation targeting the liquid-immersed and dry-type, medium-voltage product categories is scheduled in 2003. For more information, contact the California Energy Commission at tel: 916-654-4058.

3.8.2 Massachusetts Efficiency Standard

The Massachusetts Electric Industry Restructuring Act of 1997, section 313, mandates that all distribution transformers sold or installed after December 31, 1999 meet the NEMA TP 1 efficiency level.[15] The Act has resulted in improved product availability of TP 1 transformers, particularly for dry-types. Project managers indicate that electrical engineers are becoming more familiar with TP 1 through code training provided by Massachusetts Board for Building Regulations and Standards (BBRS). The standard impacts new and remodeled buildings as well as electric utilities, and is enforced by building code inspectors. For more information, contact the BBRS at tel: 617-727-3200.

3.8.3 Minnesota Procurement Efficiency Standard

The Minnesota Building Code requires that TP 1 compliant transformers be installed in new and remodeled buildings for which permit applications were received on or after July 20, 1999.[16] This standard affects both dry-type, low- and medium-voltage, single- and three-phase; and liquid-immersed, single- and three-phase transformers. The market impact for this standard is being evaluated, as the TP 1 exemption of harmonic transformers resulted in expansion of the market for K-4 units (harmonic tolerating transformers), which are often less efficient than the baseline transformers targeted by the State Building Code. Harmonic tolerating transformers are classified as "K-type" transformers, with the number after the letter K representing the severity of the harmonics the transformer can tolerate. The Department, when informed of this market development in Minnesota, consulted with manufacturers and decided to set the minimum value of K-13 as exempt (see the definition in Section 3.2 of this chapter).

Minnesota has taken steps to close this building code loophole with K-4 units by requiring documentation in the building permit application demonstrating that a harmonic transformer is legitimately needed before it can be substituted for a transformer meeting the minimum efficiency standard. For more information, contact the Minnesota Department of Public Service, tel: 651-297-2313.

3.8.4 New York Efficiency Standard

New York State adopted the TP 1 standard for commercial buildings.[17] The Energy Conservation Construction Code of New York State formally mandated the TP 1 standard starting July 2002. The Code covers dry-type, low- and medium-voltage, single- and three-phase; and liquid-immersed, single- and three-phase transformers. The Code is focused on new buildings and renovations, and compliance is enforced by state building inspectors. For more information, contact the New York Department of State, tel: 518-474-0050.

3.8.5 Oregon Efficiency Standard

Oregon is considering an amendment to its State Energy Code, which would require TP 1 transformers.[18] This standard would take effect in October 2003, and would be based on the NEMA TP 1 level for dry-type, low- and medium-voltage, single- and three-phase, distribution transformers. For more information, contact the Oregon Department of Energy, tel: 503-378-4040.

3.8.6 Vermont Efficiency Standard

The 2001 Vermont Guidelines for Energy-Efficient Commercial Construction endorse NEMA's TP 1 minimum efficiency standards.[19] The City of Burlington's Energy Code went a step further and adopted TP 1 as a mandatory standard within its jurisdiction. The mandatory standard took effect in Burlington in January 2001, and the voluntary statewide standard took effect in January 2002. The distribution transformers covered by the Burlington Energy Code and the Vermont Guidelines include dry-type, low- and medium-voltage, single- and three-phase. The inclusion of liquid-immersed transformers will be considered in the next round of code revisions. To encourage compliance and adoption, Burlington Electric is offering technical support, code training activities, and financial incentives to increase vendor and contractor awareness of the standard. For more information, contact the Vermont Department of Public Services, tel: 802-828-2811.

3.8.7 Wisconsin Efficiency Standard

The State of Wisconsin Master Specifications adopted by the Wisconsin Department of Administration require that TP 1 compliant transformers be installed in all new state facility construction and remodeling projects starting March 2000.[20] This means TP 1 is not part of the state building code, but in fact applies to state facility construction and renovation projects. The specifications cover dry-type, low-voltage, single- and three-phase distribution transformers. At present, there are no activities underway that might extend the TP 1 standard to commercial buildings. For more information, contact the Wisconsin Department of Administration, tel: 608-266-3685.

3.8.8 U.S. Congress Draft Energy Bill

Congress is considering amending the Energy Policy Act to require that low-voltage dry-type transformers manufactured on or after January 1, 2005 meet the NEMA TP 1 minimum efficiency standards. If the bill becomes law, it would regulate low-voltage, dry-type distribution transformers at the NEMA TP 1 level. This standard level would preempt the Department's Rulemaking analysis for low-voltage, dry-type transformers. For a status update on the draft Energy Policy Act amendments, contact the Committee on Energy and Commerce, the U.S. House of Representatives, tel: 202-225-2927.

3.8.9 Canadian Efficiency Standard

The Canadian Government is presently engaged in the evaluation of mandatory performance standards for distribution transformers.[21] A final rule was published for dry-type transformers (Canada Gazette, April 10, 2003), calling for compliance with efficiency values listed in Canadian Standards Association (CSA) standard C802.2-00 starting on January 1, 2005. Liquid-immersed distribution transformers may be addressed by a voluntary program, that has been drafted to allow supervisory oversight by the Canadian Government.

In June 1997, the Office of Energy Efficiency (OEE) of Natural Resources Canada (NRCan) announced that it intended to develop regulated minimum performance standards for transformers. These proposed regulations would affect interprovincial trade and transformers imported into Canada. Consultative workshops followed this announcement, which included careful consideration of harmonizing with NEMA's TP 1 levels.

The CSA drafted and published three documents, *CSA C802.1-Minimum Efficiency Values for Liquid-Immersed Distribution Transformers*, *CSA C802.2-Minimum Efficiency Values for Dry-Type Transformers,* and *CSA C802.3-Maximum Losses for Power Transformers*, which supersedes the previous *C802-94-Maximum Losses for Distribution, Power and Dry-Type Transformers*.

Some of the main points from these documents are:

- Minimum efficiency tables in C802.1 set the standard for liquid-immersed transformers in single- and three-phases at the TP 1 reference conditions, and outlined the process of applying the TOC method of evaluating losses.

- The percent efficiency in C802.2 for dry-type transformers is measured according to a per unit loading of 35 percent for low-voltage and 50 percent for medium-voltage. The efficiency levels are similar to NEMA TP 1 except the CSA added an additional significant digit (zero) in the hundredths place. For this standard, the reference winding temperature is 75°C, as in NEMA's TP 1.

- C802.3 is a voluntary standard that sets performance targets based on core and coil losses. It is not part of any mandatory programs in Canada.

As a result of the process of working with the CSA and a range of stakeholders, NRCan chose to separate the regulatory processes for liquid-immersed and dry-type transformers.

Liquid-Immersed Transformer Standards

The process of establishing minimum voluntary standards for liquid-immersed transformers took a detour after several years of development. The CSA was harmonizing the Canadian standard with NEMA's TP 1, selecting the range of regulated products, the efficiency levels and the transformer test procedures based on TP 1 and TP 2. However, a market analysis revealed that the liquid-immersed transformer market in Canada is dominated by the nine provincially-operated electric utilities, which had incorporated energy efficiency into their transformer procurement practices. It was found that more than 95 percent of the liquid-immersed distribution transformers sold in Canada already met the levels set by C802.1.

In 2000, the Canadian Government decided not to continue with the development of a mandatory national standard for liquid-immersed distribution transformers. Instead, the major Canadian utilities and manufacturers, through the Canadian Electricity Association (CEA), presented a voluntary agreement to NRCan, which is under consideration. Under the terms of this agreement, the electric utilities will report the performance of virtually all liquid-immersed transformers installed in Canada to NRCan. NRCan will then determine if the efficiency of the market is degrading, and if so, consider appropriate action. The voluntary agreement between NRCan and the liquid-immersed stakeholder group is in its final stages of completion.

Dry-Type Transformer Standards

The NRCan pre-published an amendment to the regulations that includes dry-type transformers on December 14, 2002. This prepublication gives notice of intent to regulate minimum energy performance standards for dry-type transformers manufactured after January 1,

2005. Depending on the feedback from stakeholders, NRCan may proceed with regulation of these transformers.

Dry-type transformers in Canada include a broad range of kVA ratings, greater than those of TP 1, or the Department of Energy's proposed rulemaking. The proposed definition in Canada reads that a dry-type transformer: (a) is either single-phase with a capacity from 15 to 833 kVA or three-phase with a capacity from 15 to 7500 kVA, (b) has a nominal frequency of 60 Hz, and (c) has a primary voltage of 35 kV or less and a secondary voltage of 600V or less (Canada Gazette Part 1, Vol. 136, No. 50).

See Table 3.8.1 for the percent efficiency required for dry-type transformers as taken from the standard C802.2.

Table 3.8.1 Canadian Standards for Dry-Type Transformers

Dry-Type, Single-Phase				Dry-Type, Three-Phase			
kVA	Minimum Low-Voltage, (V)	1.2 kV Class, % eff. at 0.35 of nameplate	BIL 20-150 kV, % eff. at 0.50 of nameplate	kVA	Minimum Low-Voltage, (V)	1.2 kV Class, % eff. at 0.35 nameplate	BIL 20-150 kV, % eff. at 0.50 of nameplate
15	120 / 240	97.70	97.60	15	208Y/120	97.00	96.80
25	120 / 240	98.00	97.90	30	208Y/120	97.50	97.30
37.5	120 / 240	98.20	98.10	45	208Y/120	97.70	97.60
50	120 / 240	98.30	98.20	75	208Y/120	98.00	97.90
75	120 / 240	98.50	98.40	112.5	208Y/120	98.20	98.10
100	120 / 240	98.60	98.50	150	208Y/120	98.30	98.20
167	120 / 240	98.70	98.70	225	208Y/120	98.50	98.40
250	120 / 240	98.80	98.80	300	208Y/120	98.60	98.50
333	120 / 240	98.90	98.90	500	208Y/120	98.70	98.70
500	480	-	99.00	750	208Y/120	98.80	98.80
667	480	-	99.00	1000	208Y/120	98.90	98.90
833	480	-	99.10	1500	480Y/277	-	99.00
-	-	-	-	2000	480Y/277	-	99.00
-	-	-	-	2500	480Y/277	-	99.10
-	-	-	-	3000	600Y/347	-	99.10
-	-	-	-	3750	4160Y/2400	-	99.20
-	-	-	-	5000	4160Y/2400	-	99.20
-	-	-	-	7500	4160Y/2400	-	99.20

3.8.10 Mexican Efficiency Standard

Mexico is one of the regional leaders in promoting and regulating energy efficiency. In recent years, other countries, such as Argentina, Ecuador, and Peru, have requested assistance from Mexico in the development and implementation of national efficiency programs.

Mexico began regulating distribution transformers more than two decades ago when it enacted NOM-J116 in 1977.[22] However, in 1989, a presidential decree modified the Normas Oficiales Mexicanas (Official Mexican Standards) from a mandatory to a voluntary standard; NOM-J116 became NMX-J116, a Norma Mexicana (Mexican Standard)In 1992, the Ley Federal sobre Metrología y Normalización (Federal Law on Metering and Standards) re-established the mandatory character of NOMs. In addition, this law empowered the Secretaría de Energía (the Mexican equivalent to the US Department of Energy) to formulate and enact mandatory standards for electrical equipment.

A new mandatory standard was enacted in 1994, NOM-001-SEMP-1994, to regulate the energy efficiency and safety of electrical equipment including distribution transformers. In 1997, Mexico's government proposed a revision to NOM-001, and also proposed a new standard, NOM-002-SEDE-1997.[23] NOM-002 was published in the Diario Oficial de la Federación (Official Registry) for public revision and enacted two years later in October 1999.

This standard, which regulates liquid-immersed units, is the only compulsory efficiency regulation of distribution transformers in Mexico. Dry-type distribution transformers are used in Mexico, but neither government nor industry has moved to regulate them.

Table 3.8.2 Characteristics of Regulated Distribution Transformers in Mexico

Characteristic	Specification
Power Supply	Single-phase Three-phase
Nominal Capacity	5 to 167 kVA (single-phase) 15 to 500 kVA (three-phase)
Insulation Class	Up to 15 kV Up to 25 kV Up to 34.5 kV
Installation Application	Pad; Pole; Substation; Submersible

NOM-002 provides two sets of tables with the specified minimum efficiency levels and the unit losses in watts, both tested at 100 percent of nameplate load. The next two tables presented here, Tables 3.8.3 and 3.8.4, show the efficiency requirements under NOM-002 for large manufacturers and importers of distribution transformers in Mexico. The second set, Tables 3.8.5 and 3.8.6, provide a less stringent, transitional standard for small manufacturers with cumulative annual production under 9 kVA.

The second set of tables refers to a temporary standard, established for eighteen months to ease the transition of small manufacturers to the new standard. In May 2001, with the transition period ending, officials from the Mexican Government's Energy Secretariat met with small manufacturers. These officials found that small manufacturers have not had enough time to bring their production up to the standards in NOM-002. Because these manufacturers represent an important source of employment, the Mexican Government decided to extend the transitional period for small manufacturers, without specifying the duration of this extension.[24]

While there is only one mandatory standard for distribution transformers, there are several Voluntary Mexican Standards. At this point, there are no plans to revise or propose additional standards for distribution transformers.

Table 3.8.3 Minimum Efficiency Levels for Transformers in Mexico

Type	Capacity kVA	Insulation Class		
		Up to 15 kV (%)	Up to 25 kV (%)	Up to 34.5 kV (%)
Liquid-Immersed, Single-Phase	5	97.90	97.80	97.70
	10	98.25	98.15	98.05
	15	98.40	98.3	98.2
	25	98.55	98.45	98.35
	37.5	98.65	98.55	98.45
	50	98.75	98.65	98.55
	75	98.90	98.80	98.70
	100	98.95	98.85	98.75
	167	99.00	98.90	98.8
Liquid-Immersed, Three-Phase	15	97.95	97.85	97.75
	30	98.25	98.15	98.05
	45	98.35	98.25	98.15
	75	98.50	98.40	98.30
	112.5	98.60	98.50	98.40
	150	98.70	98.60	98.5
	225	98.75	98.65	98.55
	300	98.80	98.70	98.60
	500	98.90	98.80	98.7

Note: These efficiency levels are applicable at 100 percent of nameplate load.

Table 3.8.4 Maximum Allowed Losses for Transformers in Mexico

Type	Capacity kVA	Insulation Class					
		Up to 15 kV (Watts)		Up to 25 kV (Watts)		Up to 34.5 kV (Watts)	
		Core	Winding	Core	Winding	Core	Winding
Liquid-Immersed, Single-Phase	5	30	77	38	74	63	55
	10	47	131	57	131	83	116
	15	62	182	75	184	115	160
	25	86	282	100	294	145	274
	37.5	114	399	130	422	185	405
	50	138	495	160	524	210	526
	75	186	648	215	696	270	718
	100	235	826	265	898	320	946
	167	365	1322	415	1443	425	1603
Liquid-Immersed, Three-Phase	15	88	226	110	220	135	210
	30	137	397	165	400	210	387
	45	180	575	215	587	265	583
	75	255	887	305	915	365	932
	112.5	350	1247	405	1308	450	1379
	150	450	1526	500	1630	525	1759
	225	750	2094	820	2260	900	2410
	300	910	2734	1000	2951	1100	3160
	500	1330	4231	1475	4598	1540	5046

Table 3.8.5 Transitional Standards for Small Manufacturers in Mexico

Type	Capacity kVA	Insulation Class		
		Up to 15 kV (%)	Up to 25 kV (%)	Up to 34.5 kV (%)
Liquid-Immersed, Single-Phase	5	97.50	97.40	97.30
	10	97.75	97.70	97.60
	15	97.95	97.90	97.80
	25	98.15	98.10	98.00
	37.5	98.35	98.25	98.15
	50	98.50	98.40	98.25
	75	98.60	98.50	98.40
	100	98.70	98.55	98.50
	167	98.80	98.60	98.55
Liquid-Immersed, Three-Phase	15	97.50	97.40	97.30
	30	97.80	97.70	97.60
	45	98.00	97.90	97.80
	75	98.15	98.05	97.95
	112.5	98.25	98.15	98.05
	150	98.35	98.25	98.15
	225	98.45	98.35	98.20
	300	98.50	98.45	98.25
	500	98.55	98.50	98.35

Note: These efficiency levels are applicable to manufacturers with less than 9 kVA annual production, and should be achieved at 100 percent of nameplate load.

Table 3.8.6 Transitional Maximum Losses for Small Manufacturers in Mexico

Type	Capacity kVA	Insulation Class					
		Up to 15 kV (Watts)		Up to 25 kV (Watts)		Up to 34.5 kV (Watts)	
		Core	Winding	Core	Winding	Core	Winding
Liquid-Immersed, Single-Phase	5	36	92	45	88	74	65
	10	61	169	71	164	103	143
	15	80	261	93	229	141	196
	25	110	361	123	361	176	334
	37.5	139	490	157	511	221	486
	50	166	595	190	623	254	637
	75	238	827	270	872	333	887
	100	292	1025	335	1136	385	1138
	167	439	1589	530	1841	515	1942
Liquid-Immersed, Three-Phase	15	108	277	133	267	156	260
	30	173	502	206	500	260	478
	45	218	700	259	706	316	696
	75	316	1098	374	1118	442	1128
	112.5	439	1565	501	1619	551	1686
	150	573	1944	627	2045	650	2177
	225	934	2608	1005	2770	1121	3003
	300	1141	3428	1195	3528	1380	3964
	500	1760	5597	1848	5766	2055	6333

3.9 TECHNOLOGY ASSESSMENT

A transformer is a device constructed with two primary components: a magnetically permeable core, and a conductor of a low resistance material wound around that core. A distribution transformer's primary function is to change alternating current from one voltage (primary) to a different voltage (secondary). It accomplishes this through an alternating magnetic field or "flux" created by the primary winding in the core, which induces the desired voltage in the secondary winding. The change in voltage is determined by the "turns ratio," or relative number of times the primary and secondary windings are wound around the core. If there are twice as many secondary turns as primary turns, the transformer is a step-up transformer, with a secondary voltage that would be double the primary voltage. Conversely, if the primary has twice as many turns as the secondary, the transformer is called a step-down transformer, with the secondary voltage half as much as the primary voltage. Distribution transformers are always step-down transformers.

Transformer losses are generally small, in the vicinity of a few percent or less of the total power handled by the transformer. There are two main kinds of losses in transformers: no-load (core) losses and load (winding) losses. Higher transformer efficiencies are achieved by reducing the losses associated with these two assemblies: the core and the windings.

3.9.1 Distribution Transformer Types

In general, there are two primary types of distribution transformer: liquid-immersed and dry-type. Liquid-immersed transformers typically use oil as both a coolant (removing heat from the core and coil assembly) and a dielectric medium (preventing electrical arcing across the windings). Liquid-immersed transformers are typically used only outdoors because of concerns over oil spills or fire if the oil temperature reaches the flash-point level. In recent decades, new insulating liquid insulators (e.g., silicone fluid) have been developed which have a higher flash-point temperature than mineral oil, and transformers with these liquids can be used for indoor applications. However, high initial costs for these non-flammable liquid-immersed transformers, relative to the cost of dry-type prevents wide-spread market adoption.

Dry-type transformers are air-cooled, fire-resistant devices that do not use oil or other liquid insulating/cooling media. Because air is the basic medium used for insulating and cooling and it is inferior to oil in these functions, all dry-type transformers are larger than liquid-immersed units for the same voltage and/or kVA capacity. As a result, when operating at the same flux and current densities, the core and coil assembly is larger and hence incurs higher losses. Due to the physics of their construction (including the ability of these units to transfer heat), dry-type units have higher losses than liquid-immersed units. However, dry-type transformers are an important part of the transformer market because they offer safety, environmental, and application advantages for industrial and commercial customers.

3.9.2 Transformer Efficiency Levels

There are two main kinds of losses in transformers, no-load (core) losses and load (winding) losses. Core losses are virtually constant, occurring continuously in the core material to keep the transformer energized and ready to provide power at the secondary terminals. Core losses are present even if the load on the transformer is zero. Winding losses occur in the primary and secondary windings around the core, and increase as the square of the load applied to the transformer. Winding losses result primarily from the electrical resistance of the winding material.

Figure 3.9.1 depicts the change in core and coil losses with transformer loading on a 75kVA dry-type transformer, built with copper windings and an 80 degree temperature rise.

This illustration clearly shows the exponential growth of the winding losses, in relation to the square of the load applied to the transformer.

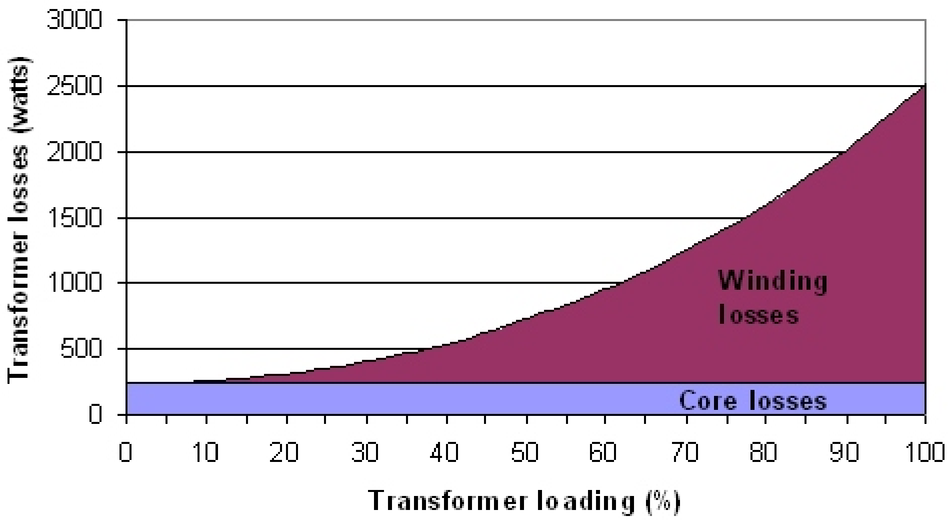

Figure 3.9.1 Transformer Losses Vary with Load (75 kVA Dry-Type)

The equation used to calculate the percent efficiency of a transformer at any loading point is given as follows (IEEE, C57.12.00):

$$EE_{load} = \left(\frac{100 \times P_{load} \times kVA \times 1000}{P_{load} \times kVA \times 1000 + NL + LL \times (P_{load})^2 \times T} \right) \qquad \textbf{Eq. 3.2}$$

where:

EE_{load}	percent efficiency at a given per unit load,
P_{load}	per unit load,
kVA	kVA rating of transformer,
NL	no load loss (Watts),
LL	load loss (Watts), and
T	temperature correction factor.

As equation 3.2 shows, the efficiency of a transformer is not a static value, but rather will vary depending on the per unit load (P_{load}) applied to the transformer. Using the losses plotted in

Figure 3.9.1, the Department used equation 3.2 to calculate the efficiency of this 75kVA dry-type transformer at each loading point from 0 to 100 percent of nameplate load. The results are shown in Figure 3.9.2, which clearly shows that the efficiency of a transformer is not static, but rather varies depending on the load applied. The apex, or highest point on the efficiency curve, occurs at the loading point where core losses are equal to winding losses.

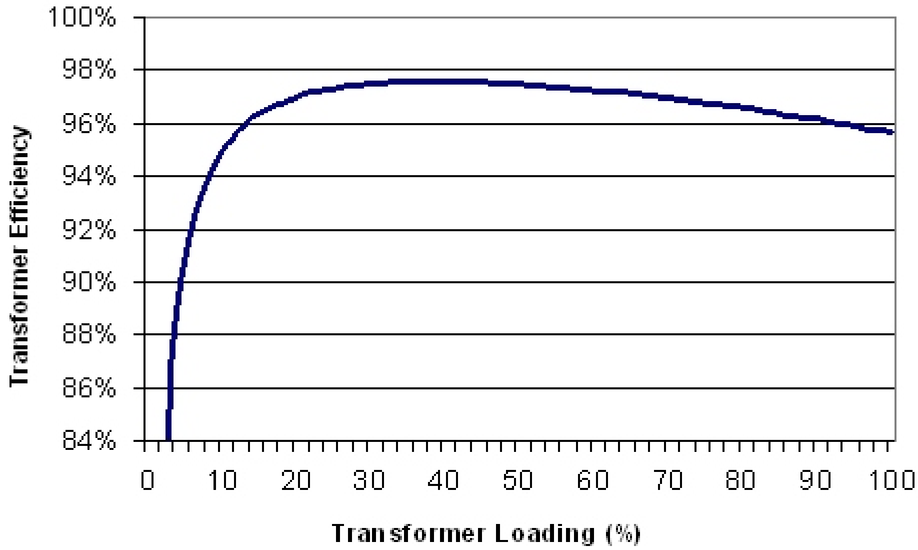

Figure 3.9.2 Transformer Efficiency Varies with Load

Consequently, any discussion of transformer efficiency must include an assumed loading point. The loading points used in the Department's analysis of distribution transformers are discussed in the energy use and end-use load characterization section of this TSD (Chapter 6).

3.9.3 Transformer Losses

This section discusses methods to reduce transformer losses that have been developed over the nearly 120 years of technology evolution, starting in 1885 with William Stanley. The physical principles of distribution transformer operation are discussed in detail in Chapter 2 of the Determination Analysis of Energy Conservation Standards for Distribution Transformers.[1] This section summarizes some of the main technological methods for reducing transformer losses.[25]

Core losses occur in the core material of the distribution transformer, and are present whenever the transformer is energized — that is, available to provide or providing load. Core losses are chiefly made up of two components: hysteresis and eddy current losses. Hysteresis losses are caused by the magnetic lag or reluctance of the core molecules to reorient themselves with the 60 Hz alternating magnetic field applied by the primary winding. Eddy current losses are actual currents induced in the core by the magnetic field, in the same manner that the field induces current in the secondary winding. However, these currents cannot leave the core, and simply circulate within each lamination, eventually becoming heat. In both instances, hysteresis and eddy current losses create heat in the core material.

Measures to reduce core losses include utilizing thinner cold-rolled oriented laminated steel (e.g., M2 or M3) or amorphous material (e.g., Metglas®). However, these measures increase the manufacturing cost. In the case of amorphous material, due to a lower maximum core flux density, larger cores must be built, which increases the winding losses.

Winding losses occur in both the primary and secondary windings when a transformer is under load. These losses, the result of electrical resistance in both windings, vary with the square of the load applied to the transformer. As loading increases, winding losses increase and are typically much more significant than core losses at levels higher than 50 percent of the nameplate loading point.

Methods of reducing winding losses tend to cause an increase in no-load losses. One method is to increase the cross-sectional area of the conductor (decreasing current density in the winding material), but that means the core has to be made larger to accommodate the larger volume of the conductor, increasing core losses. Transposition of a multi-strand conductor can also help reduce winding losses.

Table 3.9.1 was prepared by ORNL.[1] This table summarizes the methods of making a transformer more efficient by reducing the number of watts lost in the core (no-load) and winding (load). However, as previously discussed, measures taken to reduce losses in one area typically increase losses in another. This table presents those inter-relational issues, as well as the overall impacts on transformer manufacturing costs.

Table 3.9.1 Options and Impacts of Increasing Transformer Efficiency

	No-load losses	Load losses	Cost impact
To decrease no-load losses			
Use lower-loss core materials	Lower	No change*	Higher
Decrease flux density by: (a) Increasing core cross-sectional area (CSA) (b) Decreasing volts per turn	 Lower Lower	 Higher Higher	 Higher Higher
Decrease flux path length by decreasing conductor CSA	Lower	Higher	Lower
To decrease load losses			
Use lower-loss conductor material	No change	Lower	Higher
Decrease current density by increasing conductor CSA	Higher	Lower	Higher
Decrease current path length by: (a) Decreasing core CSA (b) Increasing volts per turn	 Higher Higher	 Lower Lower	 Lower Lower

*Amorphous-core materials would result in higher load losses.

The methods shown in Table 3.9.1 for making a transformer more efficient are discussed in the screening analysis (Chapter 4) and the engineering analysis (Chapter 5). The Department's analysis of the relationship between cost and efficiency for distribution transformers is presented in Chapter 5.

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